INTRODUCTION TO FLUIDS

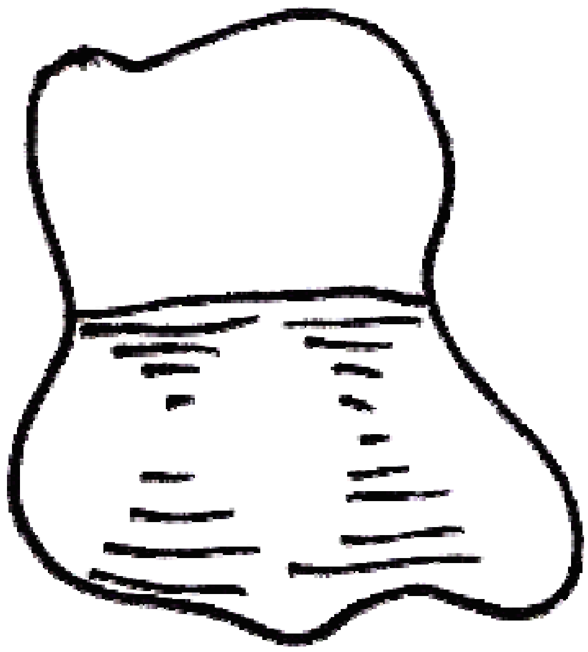
BACKGROUND and DEFINITION

Background and Definition

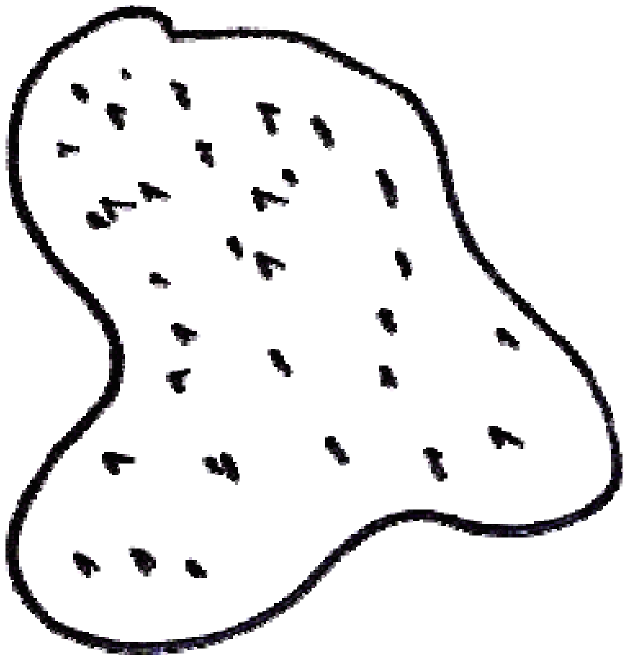
Background

- There are three states of matter: SOLIDS, LIQUIDS and GASES.
- Both liquids and gases are classified as FLUIDS.
- Fluids do not resist a change in shape. Therefore fluids assume the shape of the container they occupy.
- Liquids may be considered to have a fixed volume and therefore can have a free surface. Liquids are almost incompressible.
- Conversely, gases are easily compressed and will expand to fill a container they occupy.
- We will usually be interested in liquids, either at rest or in motion.

Background and Definition



Liquid showing free surface



Gas filling volume

Behaviour of fluids in containers

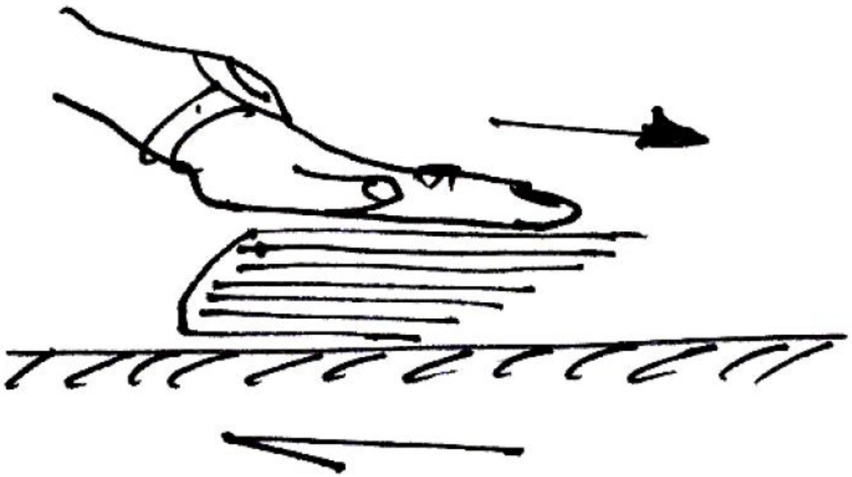
Background and Definition

Definition

The strict definition of a fluid is:

A fluid is a substance which conforms continuously under the action of shearing forces.

To understand this, remind ourselves of what a shear force is:



Application and effect of shear force on a book

Background and Definition

Definition applied to static fluids

According to this definition, if we apply a shear force to a fluid it will deform and take up a state in which no shear force exists. Therefore we can say:

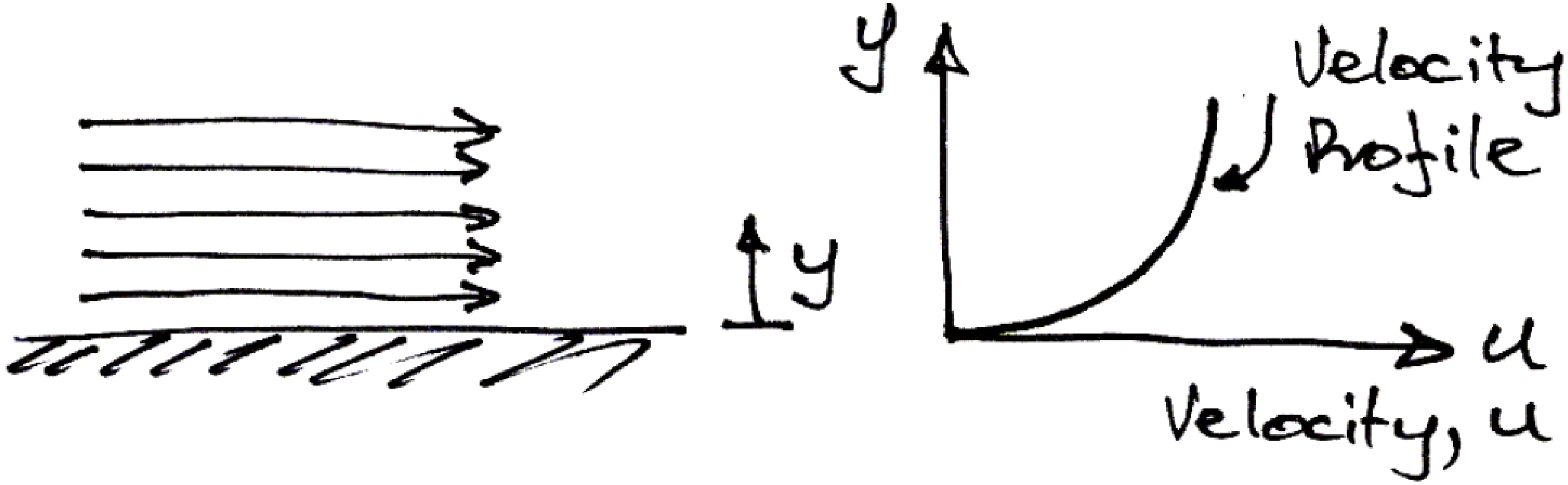
If a fluid is at rest there can be no shearing forces acting and therefore all forces in the fluid must be perpendicular to the planes in which they act.

Note here that we specify that the fluid must be at rest. This is because, it is found experimentally that fluids in motion can have slight resistance to shear force. This is the source of viscosity.

Background and Definition

Definition applied to fluids in motion

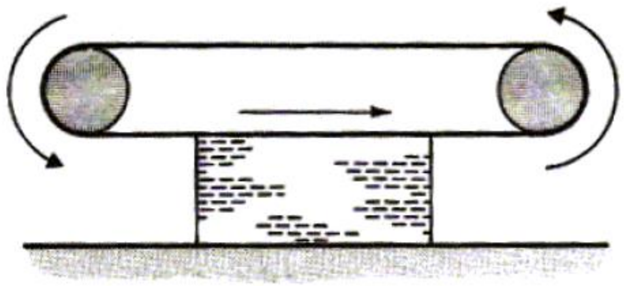
For example, consider the fluid shown flowing along a fixed surface. At the surface there will be little movement of the fluid (it will ‘stick’ to the surface), whilst further away from the surface the fluid flows faster (has greater velocity):



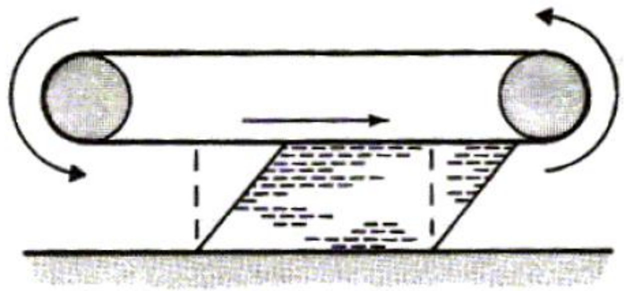
Background and Definition

Definition applied to fluids in motion

If one layer of fluid is moving faster than another layer of fluid, there must be shear forces acting between them. For example, if we have fluid in contact with a conveyor belt that is moving we will get the behaviour shown:



Ideal fluid

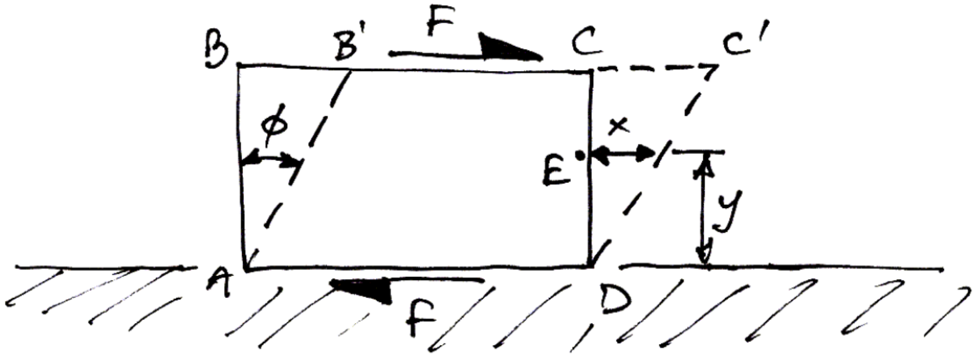


Real (Viscous) fluid

When fluid is in motion, any difference in velocity between adjacent layers has the same effect as the conveyor belt does. Therefore, to represent real fluids in motion we must consider the action of shear forces.

Background and Definition

Definition applied to fluids in motion



Consider the small element of fluid shown, which is subject to shear force and has a dimension s into the page. The force F acts over an area $A = BC \; x \; s$. Hence we have a shear stress applied:

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

$$\tau = \frac{F}{A}$$

Background and Definition

Definition applied to fluids in motion

Any stress causes a deformation, or strain, and a shear stress causes a shear strain. This shear strain is measured by the angle ϕ. Remember that a fluid continuously deforms when under the action of shear. This is different to a solid: a solid has a single value of ϕ for each value of τ. So the longer a shear stress is applied to a fluid, the more shear strain occurs. However, what is known from experiments is that the rate of shear strain (shear strain per unit time) is related to the shear stress:

$$\text{Shear stress} \propto \text{Rate of shear strain}$$

$$\text{Shear stress} = \text{Constant} \times \text{Rate of shear strain}$$

Background and Definition

Definition applied to fluids in motion

We need to know the rate of shear strain. From the diagram, the shear strain is:

$$\phi = \frac{x}{y}$$

If we suppose that the particle of fluid at E moves a distance x in time t, then, using $S = R\theta$ for small angles, the rate of shear strain is:

$$\frac{\Delta\phi}{\Delta t} = \left(\frac{x}{y}\right) \Big/ t = \frac{x}{t} \cdot \frac{1}{y}$$

$$= \frac{u}{y}$$

Background and Definition

Definition applied to fluids in motion

Where u is the velocity of the fluid. This term is also the change in velocity with height. When we consider infinitesimally small changes in height we can write this in differential form, du/dy. Therefore we have:

$$\tau = \text{constant} \times \frac{du}{dy}$$

This constant is a property of the fluid called its dynamic viscosity (dynamic because the fluid is in motion, and viscosity because it is resisting shear stress). It is denoted μ which then gives us:

Newton's Law of Viscosity:

$$\tau = \mu \frac{du}{dy}$$

Background and Definition

Generalized laws of viscosity

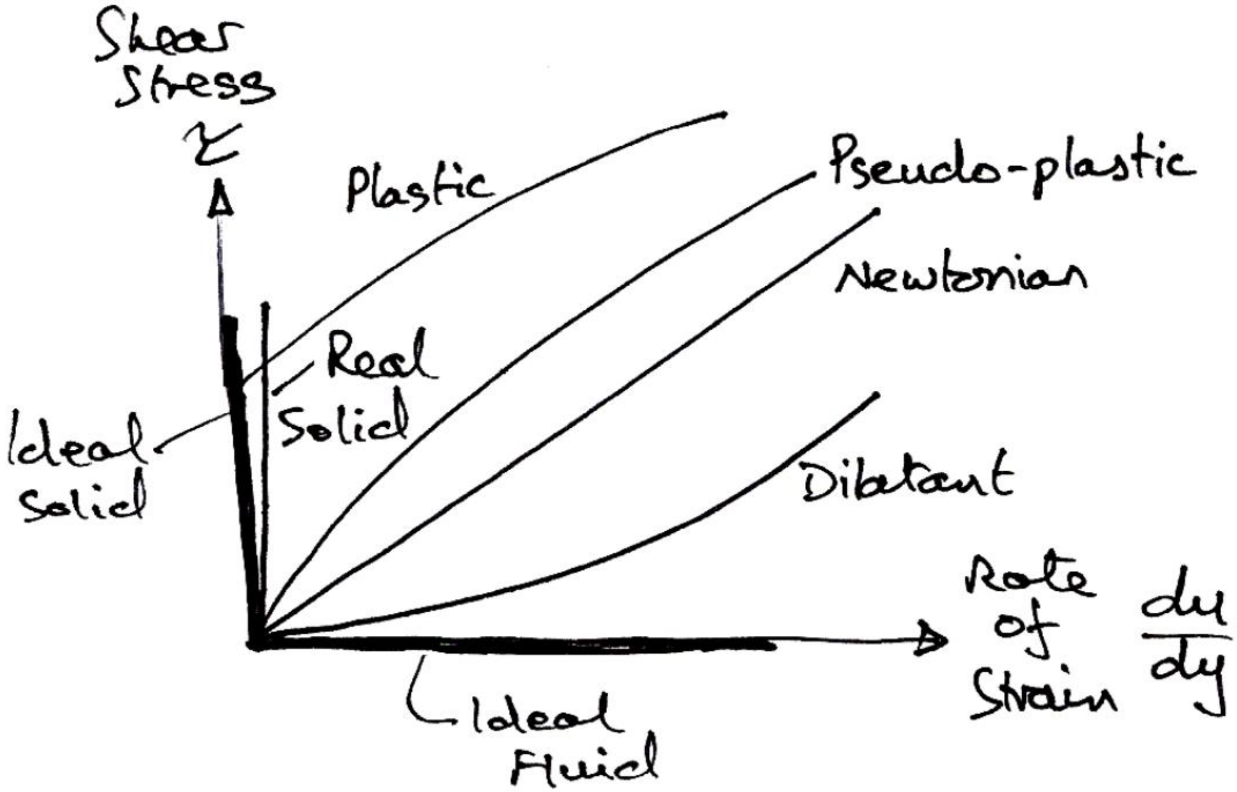
We have derived a law for the behaviour of fluids – that of Newtonion fluids. However, experiments show that there are non-Newtonian fluids that follow a generalized law of viscosity:

$$\tau = A + B\left(\frac{du}{dy}\right)^n$$

Where A, B and n are constants found experimentally. When plotted these fluids show much different behavior to a Newtonian fluid:

Background and Definition

Generalized laws of viscosity



Bahaviour of fluids and solids

Background and Definition

Generalized laws of viscosity

In this graph the Newtonian fluid is represented by a straight line, the slope of which is μ. Some of the other fluids are:

- *Plastic*: Shear stress must reach a certain minimum before flow commences.
- *Pseudo-plastic*: No minimum shear stress necessary and the viscosity decreases with rate of shear.
- *Dilatant substances*: Viscosity increases with rate of shear.
- *Viscoelastic materials*: Similar to Newtonian but if there is sudden large change in shear they behave like plastic.
- *Solids*: Real solids do have a slight change of shear strain with time, whereas ideal solids (those we idealize for our theories) do not.

Lastly, we also consider the *ideal fluid*. This is a fluid which is assumed to have no viscosity and is very useful for developing theoretical solutions. It helps achieve some practically useful solutions.